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Research Article

Change in highway transportation-induced carbon footprint of Kayseri province

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ABSTRACT

Carbon dioxide (CO_2) is the leading greenhouse gas with the greatest contribution to global warming. Ever-increasing CO_2 emissions and atmospheric accumulations result in serious global environmental problems. Limitation of greenhouse gasses causing global warming and keeping them at certain levels are under the responsibility and obligation of entire humanity. Therefore, international treaties and agreements have been established to mitigate greenhouse gas emissions and to specify the measures to be taken. Kyoto Protocol obligates signatory parties with calculation and mitigation of carbon emissions and brings them emission quotas. Countries should calculate their carbon footprints and create an inventory so as not to exceed the relevant CO_2 quotas. Countries can calculate CO_2 quantities with the use of various calculation methods. Sector-based CO_2 quantities could be calculated with the use of Tier 1, 2, and 3 methods developed by the Intergovernmental Panel on Climate Change (IPCC). In the present study, Tier 1 approach was used to calculate the transportation-induced carbon footprint of Kayseri province for CO_2, methane (CH_4), and nitrous oxide (N_2O) gases for the years 2016, 2017, 2018. The total carbon footprint for 2016, 2017, and 2018 was respectively calculated as 1726.4 Gg, 1710.58 Gg, and 1585.87 Gg CO_2.

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INTRODUCTION

Together with the ever-increasing world population and industrialization, anthropogenic environmental problems are also increasing significantly. Global warming, directly influencing the other problems and altering the climate system, is among the most significant ones of these environmental problems. The global warming issue has become a hazard to all the living individuals on this planet. Therefore, the fight against global warming problems requires a

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joint action inclusive of effort and attempt of entire humanity.

Transportation plays a key role in the acceleration of economic growth and development and improvement of living standards and quality of people. However, traffic and transportation systems have some negative aspects in terms of energy consumption and environmental impacts [1]. Since the transportation sector has significant contributions to fossil fuel consumption, it is expected to play an active role in the reduction of greenhouse gas emissions [2]. Such an impact includes one-third of global energy consumption, 40% of raw material consumption, and 30% of carbon emissions [3].

Primarily composed of carbon dioxide, methane, nitrous oxide, and chlorofluorocarbons, greenhouse gas (GHG) emissions increased by 70% from 1970 to 2004 with a great contribution to climate change and global warming. In 2004, especially CO_2 emissions constituted 77% of the total anthropogenic greenhouse gas emissions. Since these emissions largely resulted from anthropogenic activities, changes in relevant policies and behaviors may aid in the mitigation of climate change and negative impacts on human health and the environment [4]. Negative impacts of environmental pollution and global warming influence entire species. Humans have great responsibilities in the reduction of carbon emissions [5].

The Paris Agreement, adopted by 196 parties of the UN on 12 December 2015, is among the most important steps taken in combat global climate change. This treaty entered into force with the approval of 55 countries constituting 55% of global greenhouse gas emissions. This treaty to combat climate change classifies the countries as developed/developing countries and assigns them with "common, but differentiated responsibilities and relative competencies". The long-term goal of the treaty is to limit global warming below 2°C compared to pre-industrial levels [6]. As it was in this and the previous treaties, Turkey should also develop mitigation strategies for greenhouse gas emissions. Turkey's annual greenhouse gas emissions report is prepared by TURKSTAT and submitted to the UNFCCC. The updated report was submitted and disseminated to the UNFCCC on 13 April 2021 [7]. With Paris Agreement, sector-based carbon footprint calculations of the countries could be made in an accelerated fashion [8-14]. In the forthcoming days, carbon trade will be initiated for carbon mitigation. Such trade has already been initiated in airways and will widespread into all sectors for reduction of carbon emissions. Without any doubt, these measures will bring in certain limitations in business operations and the daily life of every country.

In Turkey, greenhouse gas emissions are increasing day by day. According to the 2017 greenhouse gas emission data of Turkey, the energy sector had the greatest greenhouse gas emission. Transportation-induced greenhouse gas emissions are also included in this group. In 2017, transportation-induced greenhouse gas emission was calculated as 84.7 Mt. It has been stated by the Turkish Statistical Institute that the net contribution of Turkey to the GHG emissions for the energy sector in 2018 is 88.02% as 373,101 kt CO_{2eq}. It was also stated that for the same year, CO_{2eq} emissions from transportation were 84,502 kt and this constituted 22.6% of the energy sector [15]. Highway transportation-induced air pollutant emissions exert serious threats to urban air quality and global warming. Therefore, countries and societies should develop various strategies in line with common goals and reduce their carbon emissions in the struggle with climate change [16].

In this sense, countries and societies should develop strategies for common purposes to combat climate change and should reduce carbon emissions accordingly.

In this study, carbon footprint calculations were performed based on transportation-induced CO_2, N_2O, and CH_4 greenhouse gas emissions in Kayseri province. Tier 1 approach, a calculation methodology for carbon footprint calculation recommended by Intergovernmental Panel on Climate Change (IPCC), was used to calculate transportation-induced carbon footprint between the years 2016-2017.

Carbon Footprint Calculation

Carbon footprint implies the general total of greenhouse gases generated directly and indirectly by an individual, institution or organization, or production process. Greenhouse gasses are "naturally existing greenhouse gases" and "anthropogenically generated greenhouse gases" [17]. Naturally generated greenhouse gasses include water vapor (H_2O), carbon dioxide (CO_2), ozone (O_3), methane (CH_4), and nitrous oxide (N_2O). Anthropogenic greenhouse gases include chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs) and a totally fluoride compound sulphur hexafluoride (SF_6) [18].

"Global Warming Potential" is the time-integrated radiative forcing due to a pulse emission of a given gas, over some given period (or horizon) relative to a pulse emission of carbon dioxide [19]. It indicates direct and indirect greenhouse effect generation characteristics of a unit gas in a certain time frame relative to CO_2, selected as a reference gas. Highway transportation consumes about 76% of total oil consumption in the transportation sector; on the other hand, railway transportation consumes only 1% of total oil consumption. In EU countries, urban transportation is responsible for 23% of greenhouse gas emissions. While highway transportation releases 72.8% of greenhouse gasses, railway transportation has only 0.6% contribution to greenhouse gas emissions. In terms of CO_2 emissions, the transportation sector has the greatest contribution [20]. In other words, it expresses how many times more heat retention capacity of other greenhouse gases except CO_2 can be compared to the same amount of CO_2. In this way, a common expression is used for all greenhouse gasses. According to Table 1, although sulfur hexafluoride has the greatest global warming potential, CO_2 has the lowest value. However, in terms of emissions, CO_2 has the greatest quantity [17, 21, 22]. According to IPCC assessment reports, global warming potentials may change from time to time because of the changes in internal, external, and natural climate systems of the world. Estimations of the International Energy Agency (IEA) revealed that the primary energy demand of the world will increase by about 40% between the years 2007 – 2030. When the emission reductions were compared with the increases in energy demands, it was seen that there was much to do to combat global warming [23].

Kayseri is located in central Turkey with a 16,970 km^2 area that consists of eleven district municipalities and five metropolitan sub-provincial municipalities. Kayseri is the 15th most populous region in Turkey with a total population of 1,407,409 residents with about 1100 tons of generated municipal solid waste per day and one of the most industrialized provinces of Turkey [24]. Due to all these strategically important features, Kayseri province has been chosen as the target region in this study. In Table 2, some data for vehicles registered in traffic in Kayseri province was provided.

Kayseri is one of the biggest cities of Turkey with a 17,193 km^2 surface area, 1,322,376 population, and 972 industrial manufacturer companies. As seen in Figure 1, it is placed near the center of Turkey [26].

Kayseri is one of the foreground cities in Anatolia, which indicates the importance of industry and production for the city [27]. Due to the high population density and high commercial capacity of Kayseri province, the city was selected as a target region in this study.

There are various guidelines to be used in greenhouse gas emissions of the countries or organizations. These guidelines include IPCC, ISO 14064, and UNFCCC-like standards. According to IPCC guidelines, three different Tier approaches are used in the calculation of footprints for greenhouse gas emissions [18, 29].

THEORY

Present data were obtained from the fuel consumption measurement results of the Energy Market Regulatory Authority (EPDK) for Kayseri province [30]. With the aid of the Tier 1 method, the total CO_2 footprint quantity of CO_2, N_2O, and CH_4 combustion gases was determined. In Table 3, Transportation-induced Fuel Consumption Data for Kayseri province was given.

In the present study, Tier 1 method, the simplest approach, was used to calculate the transportation-induced carbon footprint of Kayseri province. This method of calculation is constructed on the calculation of CO_2 quantity generated through the burning of fuel used in the transportation sector. Calculations are performed based on the assumption "if A quantity of fuel (coal, natural gas, crude oil, etc.) was used, then B quantity emission is expected".

CO_2 emissions are calculated as follows:

1. Identification of amount of fuel used,
2. Identification of energy content based on fuel type and consumption.
3. Selection of proper carbon dioxide emission factors based on fuel type and calculation of total carbon

Table 1. Global Warming Potentials (GWP) of Greenhouse Gasses [25]

Greenhouse Gases	Global Warming Potential		
	The second assessment report (SAR)	The fourth assessment report (AR4)	The fifth assessment report (AR5)
CO_2	1	1	1
CH_4	21	25	28
N_2O	310	298	265
SF_6	23,900	22,800	23,500

Figure 1. Location of Kayseri in Turkey [26].

Table 2. Type and number of vehicles registered in traffic in Kayseri province [28]

Years	Total	Automobile	Minibus	Bus	Pickup	Truck	Motorcycle	Special-purpose	Tractor
2018	374889	235194	6302	4884	63737	16707	17441	854	29770
2017	364415	228920	6214	4822	61477	16518	16621	808	29035
2016	345020	215843	6070	4618	57666	16400	15880	731	27812

dioxide quantity within consumed fuel with the use of these factors.

The most common fuels used in highway vehicles and conversion factors for these fuel types are provided in Table 4. Carbon dioxide emission factors for the same fuel types are provided in Table 5.

$$\text{Energy Consumption [TJ]} = \text{Fuel Consumption [t]} \times 103 \times \text{Conversion Factor [TJ/kt]} \quad (1)$$

$$\text{Carbon Content[Gg C]} = \text{Carbon Emission Factor [kg/TJ]} \times \text{Energy Consumption [TJ]} \quad (2)$$

$$\text{Carbon Emission[Gg C]} = \text{Global Warming Potential} \times \text{Carbon Content[Gg C]} \quad (3)$$

$$\text{CO2 Emission Quantity[Gg CO2]} = \text{Carbon Emission [Gg C]} \times 44/12 \quad (4)$$

In the calculation of emission quantity, the stoichiometric effect of CH_4 and N_2O gases as the final products should be calculated and then total CO_2 quantity should be determined. In this calculation, emission factors of methane and nitrous oxide gases are taken into consideration (Table 6).

Finally, to calculate the potential effect on global warming, gas quantity is multiplied by the potential effect of each gas provided in Table 1. The global warming potential values in the fifth assessment report (AR5) were given in the formula below (Eq. 5).

$$\text{GWP(CO2,CH4,N2O)[Gg CO2]} = \text{GWP value} \times \text{CO2 Emission Quantity[Gg CO2]} \quad (5)$$

Table 3. Transportation-induced Fuel Consumption Data for Kayseri province (ton) [28]

Year	Fuel Type	Fuel Consumption (ton)
	Gasoline	34,398
2018	Diesel	385,445
	LPG	96,381
	Gasoline	34,092
2017	Diesel	381,513
	LPG	95,898
	Gasoline	31,720
2016	Diesel	347,105
	LPG	95,545

Table 4. Conversion factors are determined based on the net calorie values of the fuels [18]

Fuel Type	Conversion Factor (TJ/kt)
Gasoline	44.80
Diesel	43.33
Liquid Petroleum Gas (LPG)	47.31

RESULTS AND DISCUSSION

The data provided in Table 3 were used in Equations (1-4) to calculate transportation-induced CO_2 emissions in Kayseri province and results are provided in Table 7. In the calculation of CO_2 emissions, emissions were separately calculated for CO_2, CH_4, and N_2O gases, and CO_2 emission equivalents were then calculated. The relative position of Kayseri province in terms of petroleum products and LPG utilization in the average of Turkey is presented in Figure 2.

Turkey signed the Paris Agreement on 22[nd] of April, 2016 together with 175 countries under the framework of the UN in New York and committed 21% reduction in greenhouse gas emissions in transportation, energy, industrial processes, land-use change, forestry, and waste sectors between the years 2021 – 2030 [31].

For Kayseri province between the years 2016-2018, the total carbon quantity originated from CO_{2eq} emissions was calculated as 4.702,101 Gg CO_{2eq}. In 2016, emissions were calculated as 1483.970 Gg CO_{2eq} for CO_2, 39.609 Gg CO_{2eq} for CH_4, and 27.90 Gg CO_{2eq} for N_2O. In 2017, emissions were calculated as 1601.633 Gg CO_{2eq} for CO_2, 40.673 Gg CO_{2eq} for CH_4, and 68.275 Gg CO_{2eq} for N_2O. Finally, in 2018, values were calculated as 1616.498 Gg CO_{2eq} for CO_2, 40.933 Gg CO_{2eq} for CH_4, and 68.967 Gg CO_{2eq} for N_2O. The total CO_2 emission footprint of greenhouse gases was calculated as 1585.87 Gg CO_{2eq} for 2016, 1710.581 Gg CO_{2eq} for 2017, and 1726.398 Gg CO_{2eq} for 2018. The variation of

Table 5. Carbon dioxide Emission Factors [18]

Fuel Type	Emission Factor (TC/TJ)	Carbon Oxidation Ratio
Gasoline	18.9	0.99
Diesel	20.2	0.99
LPG	17.2	0.995

Table 6. Emission factors of CH_4 and N_2O (kg/TJ) [18]

Fuel Type	CH_4	N_2O
Gasoline	33	3.2
Diesel	3.9	3.9
LPG	62	0.2

Table 7. Fuel Consumption-Originated Carbon Footprint Quantity of Kayseri Province

Year	CO_2							
	Fuel Type	**Fuel Consumption (ton)**	**Conversion Factor (TJ/kt)**	**Carbon Emission Factor (tC/TJ)**	**Carbon Oxidation Rate**	**Global Warming Potential**	**Carbon Emission (Gg C)**	**CO_{2eq} Emission (Gg CO_{2eq})**
	Gasoline	34,398	44.8	18.9	0.99	1	28.834	105.7
2018	Diesel	385,445	43.33	20.2	0.99	1	333.993	1224.6
	LPG	96,381	47.31	17.2	0.995	1	78.036	286.1
							Total Transportation Induced Emission Value	**1616.5**
	Gasoline	34,092	44.8	18.9	0.99	1	28.578	104.8
2017	Diesel	381,513	43.33	20.2	0.99	1	330.586	1212.2
	LPG	95,898	47.31	17.2	0.995	1	77.645	284.7
							Total Transportation Induced Emission Value	**1601.6**
	Gasoline	31,720	44.8	18.9	0.99	1	26.589	97.5
2016	Diesel	347,104	43.33	20.2	0.99	1	300.771	1102.8
	LPG	95,545	47.31	17.2	0.995	1	77.359	283.7
							Total Transportation Induced Emission Value	**1483.9**
	CH_4							
	Fuel Type	**Fuel Consumption (ton)**	**Conversion Factor (TJ/kt)**	**Carbon Emission Factor (tC/TJ)**	**Global Warming Potential**		**Carbon Emission (Gg C)**	**CO_2eq Emission (Gg CO_{2eq})**
	Gasoline	34,398	44.8	33	28		1.424	5.2
2018	Diesel	385,445	43.33	3.9	28		1.824	6.7
	LPG	96,381	47.31	62	28		7.916	29
							Total Transportation Induced Emission Value	**40.9**
	Gasoline	34,092	44.8	33	28		1.411	5.2
2017	Diesel	381,513	43.33	3.9	28		1.805	6.6
	LPG	95,898	47.31	62	28		7.876	28.9
							Total Transportation Induced Emission Value	**40.7**
	Gasoline	31,720	44.8	33	28		1.313	4.8
2016	Diesel	347,104	43.33	3.9	28		1.642	6
	LPG	95,545	47.31	62	28		7.847	28.8

						Total Transportation Induced Emission Value	**39.6**
	N_2O						
	Fuel Type	**Fuel Consumption (ton)**	**Conversion Factor (TJ/kt)**	**Carbon Emission Factor (tC/TJ)**	**Global Warming Potential**	**Carbon Emission (Gg C)**	**CO_{2eq} Emission ($Gg\ CO_{2eq}$)**
	Gasoline	34,398	44.8	3.2	265	1.307	4.8
2018	Diesel	385,445	43.33	3.9	265	17.261	63.3
	LPG	96,381	47.31	0.2	265	0.242	0.9
						Total Transportation Induced Emission Value	**68.9**
	Gasoline	34,092	44.8	3.2	265	1.295	4.8
2017	Diesel	381,513	43.33	3.9	265	17.085	62.6
	LPG	95,898	47.31	0.2	265	0.240	0.9
						Total Transportation Induced Emission Value	**68.3**
	Gasoline	31,719	44.8	3.2	265	1.205	4.4
2016	Diesel	347,105	43.33	3.9	265	15.544	56.9
	LPG	95,545	47.31	0.2	265	0.240	0.9
						Total Transportation Induced Emission Value	**62.3**

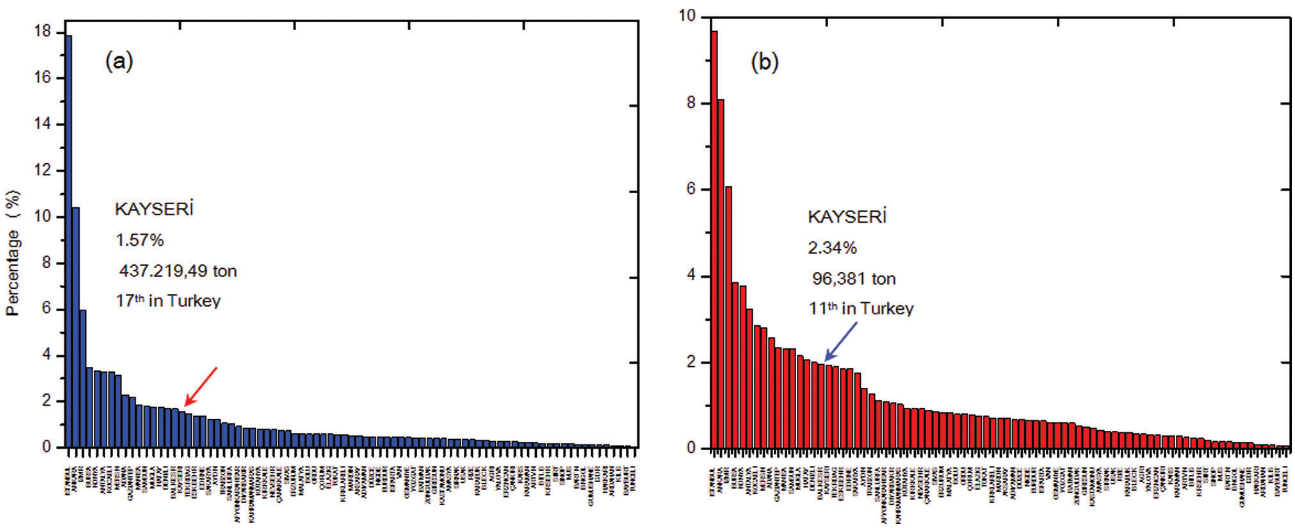

Figure 2. Province-based (a) Petroleum and (b) LPG consumptions in Turkey [30].

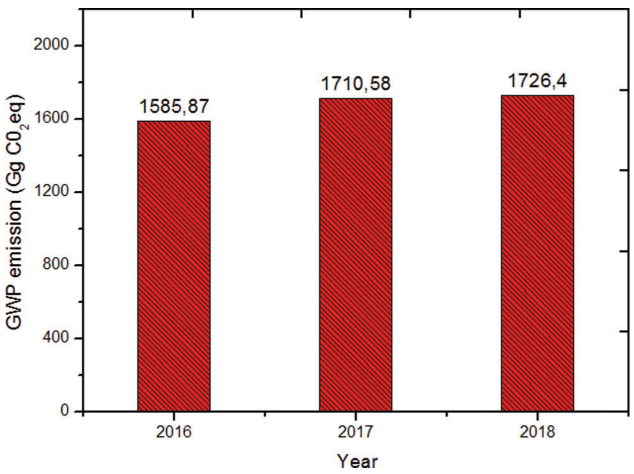

Figure 3. Variation of GWP CO2eq Emission in Kayseri city.

GWP CO_{2eq} Emission in Kayseri city as a function of years is illustrated in Figure 3

Greenhouse gas emissions of some other provinces of Turkey were studied previously. For instance, transportation-induced CO_2 footprint was reported as 1453.954 Gg for Eskisehir province in 2016 [32], as 471.84 Gg for Isparta province in 2016 [33] and Sivas province as 683.17 Gg CO_{2eq} in 2016, 736.26 Gg CO_{2eq} in 2017, and 783.26 Gg CO_{2eq} in 2018 [17].

The N_2O and CH_4-induced total carbon quantities were respectively calculated as 199.533 and 121.215 Gg CO_{2eq}. Nakamoto et al. (2019) investigated the relationships of global CO_2 quantities with vehicle age and reported transportation-induced carbon footprints of the USA, Germany, and Japan respectively as 13.3 Mt CO_{2eq}, 8.1 Mt CO_{2eq}, and 7.2 Mt CO_{2eq}. Researchers reported carbon footprints of Australia and Finland, with high vehicle age average, respectively as 0.31 Mt CO_2 and 0.05 Mt CO_2 [34]. Coşkun and Oktay (2020) conducted a study in Turkey to investigate vehicle-induced carbon footprint and reported vehicle-induced carbon footprint in 2016 as 217.77 Mt CO_{2eq}. Researchers reported that Istanbul had the greatest carbon footprint (0.108 Mt CO_{2eq}) and Tunceli province had the lowest value [35].

Petroleum and LPG-induced carbon emissions of Kayseri province were respectively calculated as 437.219,49 ton (17th in Turkey) and 96.381 ton (11th in Turkey) and these values were around the country averages (Figure 1).

CONCLUSION

The transportation-induced CO_2 footprint of Kayseri province was calculated with the use of the above-given equations and the Tier 1 approach. Data were supplied from TUİK and Energy Market Regulatory Authority.

There are recent increases in both the number of vehicles and fuel consumptions in Kayseri province. Carbon footprint calculations conducted with the use of the Tier 1 approach and resultant values are provided in this study. As can be inferred from the results, there is an increase in total greenhouse gas emissions between the years 2016 – 2018.

Increasing CO_2 footprints were observed with increased fuel consumption. According to 2018 TUİK data, Kayseri province had 17th rank in petroleum consumption and 11th in LPG consumption. It was inferred from these values that Kayseri province had 1.57% contribution to the country's CO_2 footprint for petroleum consumption and 2.32% for LPG consumption. As it was in all sectors, measures should be taken also in the transportation sector to mitigate carbon emissions. Considering the sustainable urbanization against global climate change, the following measures could be recommended to mitigate CO_2 emissions and the negative effects of global warming;

- Development of low carbon emission technologies and mitigate the utilization of fossil fuels like petroleum, natural gas, and coal.
- Utilization of low CO_2 emission fuels and development of hybrid technologies.
- Increasing the use of bioenergy-originated fuels in transportation.
- Increasing the capacity of sink area (afforestation, forestation, wetlands, marshes, etc).
- Increasing the use of renewable energy resources as fuel.
- Promotion of public transportation.

Insufficient institutional and financial capacity in the transport sector is one of the important results of the underdevelopment of public transport in most Turkey cities including Kayseri. This can only be solved by establishing strong political willingness in urban transport policy-making to overcome the private lobby pressure.

To reduce carbon footprint in the city, the first and important thing that the Government should do in this regard is to improve public transportation systems in the city, so that more and more people switch to public modes. Another important step to minimize carbon emission is to inform the public about carbon footprint. By providing awareness about carbon emissions, the public should be encouraged to turn to carbon-free modes of transportation, such as public transportation, electric vehicles, or bicycles that do not cause carbon emissions, rather than the use of private vehicles unless necessary. It is also thought that giving the public the habit of walking or cycling short distances will provide a significant decrease in carbon emissions.

Besides, it is very important to make consumers informed of the impact of their preferences and actions, and the possible ways of reducing their carbon footprint, through the media and public activities.

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